

Membrane Structure

5 The present invention relates to a membrane structure with improved performance characteristics which is particularly useful for zeolite membranes.

10 A commonly used membrane structure for separating two components consists of a tubular membrane with the mixture being passed down the tube and a separated component passing through the membrane and the other component or mixture of components passing down the tube. The tube can be bent so that it is in the form of a continuous zig-zag or other convoluted or similar configuration to increase the surface area of the tube contained in a module.

15 Alternatively or in addition there can be a plurality of tubes arranged substantially in parallel to increase the surface area of membrane without having too large a diameter of each tube or tube length.

20 In a module for use in separation or filtration processes using tubular membranes, the size and configuration of the membranes is chosen so that the optimum performance can be achieved. For a tubular membrane, the larger the diameter of the tube the greater the surface area per unit length of the tube and the lower the pressure drop down the tube, this is normally a desired criterion. However the larger the diameter of the tube, the greater the possibility, at any given flow rate of streamline flow down the tube and the greater the distance from the centre of the tube to the membrane and  
25 these will lead to a corresponding loss of performance. Whereas a narrower tube gives a lower surface area per unit length, and requires a lower flow rate to give the same degree of turbulence, but gives a higher pressure drop. In order to balance these characteristics, a series of parallel tubes in a module can be used, with the diameter of each tube chosen for optimum performance and the number of tubes chosen to have  
30 the desired surface area in the module.

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5 With ceramic membranes it is cost efficient and convenient to form a plurality of tubes together in the form of a monolith. Hence monolithic assemblies of tubes have been developed wherein a single, tubular body comprises a multiplicity of smaller channels.

10 The number and shape of the inner channels can vary. For example, monoliths with 7, 19 or a greater number of channels have been developed as well as monoliths with star or other shaped channels. Typically, such designs have been developed so as to maximise the surface area per unit length of monolith, combined with minimum pressure drop whilst maintaining high overall permeability.

15 We have found that a particular arrangement of tubular membranes gives unexpectedly superior results for zeolite membranes in pervaporation over what would have been expected.

20 According to the invention there is provided a comprising a tubular porous ceramic monolith having at least four tubular conduits formed within the monolith with a zeolite membrane formed on the internal surface of the conduits the zeolite membranes having an internal diameter of 5 to 9 millimetres preferably 6.4 millimetres and the ceramic monolith having an outer diameter of 20 to 25 millimetres, preferably 20mm.

25 In practice the internal diameter will vary along the length of the tubular membrane and will vary according to membrane thickness, so the internal diameter of the tubular membranes is an approximate average along the length of the tube and the invention will encompass structures which deviate from the exact measurements in accordance with normal practice.

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The length of the porous ceramic monolith will depend on the use to which the zeolite membrane is to be used and the vessel into which it is to be fitted. In general lengths of from 1 to 10 metres are useful in many applications.

- 5 The tubular zeolite membrane is preferably formed by the methods disclosed in our co-pending patent applications PCT/GB96/00243, PCT/GB97/00928 and PCT/GB 97/00635.

- 10 Typical zeolites which can be used in the present invention include but are not limited to, 3A, 4A, 5A, 13X, X, Y, ZSM5, MPOs, SAPOs, Silicalite, etc.

- 15 The porous supports on which zeolite membranes are formed are preferably formed of sintered ceramic powders such as alpha alumina, titania, zirconia or other suitable media which are capable of being extruded and sintered upon which the zeolite will nucleate and grow.

- 20 The present invention can be used with porous supports of any suitable size although, for large flux rates through a membrane, large pore sizes are preferred. Preferably pore sizes of 0.01 to 2,000 microns, more preferably of 0.1 to 200 and ideally of 0.1 to 20 microns are used. Pore sizes up to 300 microns can be determined by bubble point pressure as specified in ISO 4003. Larger pore sizes can be measured by microscopic methods.

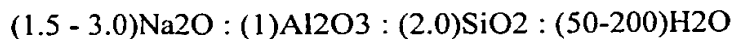
- 25 The membranes which can be used in the present invention can be formed by any method, for example by crystallisation from a gel or solution, by plasma deposition or by any other method such as electro-deposition of crystals on conducting substrates e.g. as described in DE 4109037.

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When the membrane comprising a film of a zeolite material is prepared by crystallisation from a synthesis gel, any of the methods described in the prior art can be used.

- 5 The synthesis gel used in the process can be any gel which is capable of producing the desired crystalline zeolite membrane. Gels for the synthesis of zeo-type materials are well known and are described in the prior art given above or, for example, in EP-A-57049, EP-A-104800, EP-A-2899 and EP-A-2900. Standard text books by D W Breck ("Zeolites Molecular Sieves, Structure Chemistry and Use") published by John Wiley (1974) and P.A Jacobs and J.A Martens (Studies in Surface Science and Catalysis No. 33, Synthesis of High Silica Alumino silicate Zeolites" published by Elsevier (1987), describe many such synthesis gels. The process which can be used includes conventional syntheses of zeolite membranes, except that the synthesis is carried out in the presence of the porous support. Most commonly, gels are crystallised by the application of heat.

The membrane can be prepared by a process which comprises deposition or crystallisation from a growth medium. One method for forming the membrane preferably has a molar composition in the range of



and the method used can be used in any of the methods disclosed in the references listed above

- 25 The conditions which can be used for forming the membrane are with a temperature of the growth solution preferably in the range of 50 to 100°C and the pH can be adjusted e.g. to pH of 12.5 to 14 by addition of sodium hydroxide or ammonia. If desired the sodium ion concentration can be increased without increasing the pH by the addition of a sodium salt such as sodium chloride. The growth solution can be

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seeded with zeolite crystals of the desired zeolite to be synthesised. The membrane can be washed to pH neutral after membrane formation prior to any post-treatment.

5 The porous support can be contacted with the growth medium by immersion or by pouring the growth medium over the support with the support held substantially horizontal, either face up at the bottom of a container, or face down at the surface of the growth medium, or it can be passed over one or both sides of the support, with the support held substantially horizontal, or it can be passed over one or both sides of the support with the support held substantially vertical or the support can be in any  
10 intermediate position.

The growth medium can be kept static, stirred, tumbled or passed over or around the support, alternatively the growth medium can be passed over both sides of the support with the support held substantially horizontal or at any intermediate position.

15 Pressure may also be applied but it is usually convenient to conduct the crystallisation under autogenous pressure. Preferably the porous support is completely immersed in the growth medium; alternatively, if desired, only one surface of the support may be in contact with the growth medium. This may be useful, for example,  
20 if it is desired to produce a membrane in the form of a tube, where only the inside or outside of the tube need be in contact with the growth medium.

It may be useful if it is desired to produce a membrane containing two different zeolites, one on each side of the support. Use of such a bi-functional membrane  
25 would be equivalent to using two separate membranes, each carrying a different zeolite.

If desired, the treatment with the gel can be repeated one or more times to obtain thicker membrane coatings.

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Preferably the porous support is pre-treated with a zeolite initiating agent. The zeolite initiating agent is preferably a cobalt, molybdenum or nickel oxide or it can be particles of a zeolite, e.g. the zeolite which it is intended to deposit on the porous support, or any combination of these. Another example of an initiating agent is a compound which can deposit a zeo-type pre-cursor material e.g. a silicic acid or polysilicic acid.

The zeolite initiation agent can be contacted with the porous support by a wet or dry process. If a dry process is used, the particles of the zeolite initiation agent can be rubbed into the surface of the porous material, or the porous material surface can be rubbed in the particles.

Alternatively the particles of the zeolite initiation agent can be caused to flow over and/or through the porous support, or pulled into the support by means of a vacuum.

If a wet process is used, a liquid suspension of powder of the zeolite initiation agent is formed and the liquid suspension contacted with the porous support to deposit the zeolite initiation agent on the support.

Before contacting the surface of the porous support with the zeolite initiation agent the surface is preferably wetted with wetting agent such as an alcohol, water or a mixture of these.

After formation the membrane is preferably treated with a surface modifying agent which can cross link with the zeolite membrane and thus form a membrane with substantially no defects. The preferred surface modifying agents are silicic acid and silicates such as alkyl silicates e.g. tetra ethyl orthosilicate (TEOS).

In the present specification by silicic acid is meant monosilicic, low, medium and high molecular weight polysilicic acids and mixtures thereof.

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Methods of making silicic acids are described in GB Patent Application 2269377.

5 The silicic acids used can have a "narrow" molecular weight distribution as formed or in a combination of different molecular weight ranges.

Greater flexibility can be introduced into the final membranes by treating them with a flexibilising agent by adding e.g. a hydroxy terminated polysiloxane into the silicic acid solution before treatment of the membrane.

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The membrane structures of the present invention can be used in a range of separation and catalytic processes, e.g. dehydration of LPG, air, alcohols and natural gas, removing linear alkanes, olefins and substituted hydrocarbons from mixtures with branched chain compounds, e.g. in reforming, dewaxing, etc., hydrogenation and

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dehydrogenation of linear hydrocarbon in admixture with branched chain compounds.

The invention is described in the Example.

## 20 Example

A ceramic substrate of the structure of fig.1 of the drawing was pre-treated so as to deposit zeolite 4A powder on the inside of the channels using the following method.

25 The outer ceramic tube (1) had a diameter of 20mm and the inner tubes (2) had a diameter 6.4mm

An appropriate sized pipe cleaner, which had been loaded with zeolite 4A particles (nominally sized 2-5µm) was inserted into one channel of a porous ceramic tube 60

30 cm long by 20 mm overall diameter with four channels each 6.4mm diameter and fed

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through the bore of one channel until it emerged out of the other end (the pipe cleaner was twisted to form a stiffer rod so as to aid insertion through the tube). The pipe cleaner was pulled backwards and forwards through the channel effecting a deposit of 4A particles on the internal walls of the channel. This was repeated for each of the

5 remaining three channels.

By this method of powder deposition, between  $0.435 \times 10^{-4}$  and  $2.39 \times 10^{-4}$  g/cm<sup>2</sup> of powder were deposited on the total surface of the ceramic support. The total weight of powder deposited was found to vary with the pore size of the ceramic support.

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#### Membrane growth procedure

The zeolite membrane was formed on the inside of the four pre-treated channels by allowing a hydrogel suspension to be in contact with the surfaces under the conditions

15 described below.

The hydrogel is formed by combining two separate solutions, (solution A) and (solution B ) to form a homogeneous suspension.

#### 20 Solution A

24.49g Sodium Aluminate, 3.75g Sodium Hydroxide and 179.74g de-ionised water were mechanically shaken until dissolved. The Sodium Aluminate had an actual composition 62.48% Al<sub>2</sub>O<sub>3</sub>, 35.24% Na<sub>2</sub>O, and 2.28% H<sub>2</sub>O.

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#### Solution B

50.57g Sodium Silicate of composition 14.21% Na<sub>2</sub>O, 35.59% SiO<sub>2</sub> and 50.20% H<sub>2</sub>O was dissolved in 148.8g de-ionised water.

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Solution A was heated to 50°C and added slowly to solution B which had been pre-heated to 90°C with stirring to ensure complete and even mixing (it is important that no lumps of hydrogel are formed). The mixture was then heated to 95°C. This resulted in a hydrogel having a molar composition

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2.01 Na<sub>2</sub>O : Al<sub>2</sub>O<sub>3</sub>: 2.0 SiO<sub>2</sub> : 143.10 H<sub>2</sub>O

The pre-treated tube was wetted by immersing it in deionised water for 15 seconds. The tube was then suspended vertically above the bottom of the growth vessel. Hot hydrogel was then added to the growth vessel, care being taken to ensure that all the air was expelled from the channels .

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The growth vessel was sealed and heated to 100°C for 5 hours.

After 5 hours the tube was removed from the growth vessel, allowed to cool slightly and then removed and washed clean using deionised water over a period of 16 hours. The ceramic tube was then dried at 100°C for 6 hours.

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X-ray Analysis showed this to be a Zeolite 4A.

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A mixture of polysilicic acids of mean molecular weight of about 800 was diluted with ethanol to 5% wt. solids. 500ml. of this solution was circulated over the feed side of the membrane and drawn through the membrane to treat the surface whilst being heated to 70° C., with vacuum for 5 hours to cross-link the silicic acid in the pores of the membrane.

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A comparison of the performance of the four channelled monolith with that of a single narrow tube in water separation from a water/isopropanol mixture at 70°C. Care was taken to ensure that the tubes were tested under identical conditions of turbulence of the feed solution and the results shown below.

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Tube Type	Water Flux Kg/ m <sup>2</sup> /day At Re8582 and 2% wt Water/ IPA at 70°C	Number of tubes per m <sup>2</sup>	Tube price per m <sup>2</sup> at £100 each	£/Kg water removed
4 Channel	21	22	2200	200
Narrow bore	41	100	10,000	243.9

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The tube dimensions were

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	Tube Diameter mm	Tube Inner Circumference mm	Tube area per 58cm length
4 channel	4 x 6.4	7.92	459
Narrow Bore	1 x 5.5	1.728	100.2

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As can be seen the four tube configuration is surprisingly superior in performance and cost per unit area of membrane.